Enhancing Operations by Applying Constructive Simulation and Artificial Intelligence

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ABSTRACT

Department of defense, homeland security, and law enforcement agencies are facing increasing complexity, namely operational and tactical units are assigned larger geographical areas of responsibility with less personnel. As operations accelerate, decision cycles become shorter. At the same time, the spectrum of tasks becomes broader as operations are conducted across various dimensions (e.g. cyber operations, electro-magnetic spectrum operations), joint and combined forces have to be coordinated. With operations taking place "amongst the people", soldiers and law enforcement operatives must not only act as troopers, but also as "armed social workers". This paper focusses on the Command and Control (C2) process as central element of operations. It describes use cases of integrating Artificial Intelligence (AI) and data analysis in the C2 process, supported and enabled by Constructive Simulation (CS) as modelling and simulation backbone. Use cases include Applying Artificial Intelligence in the Command and Control Process (AI4Op), Constructive Simulation within an AI Development Environment (Sim4AI), Provision and Simulation of AI Services (SimOfAI) and Support of Constructive Simulation by Automation (AI4Sim). The paper shows how constructive simulation systems can be utilized today and in future for the development and testing of respective AI-based C2 services to support current and future operations by promoting the integration of assets across different disciplines. Finally, the paper reflects on architectural challenges when integrating Artificial Intelligence, Constructive Simulation and Command and Control Information Systems (C2IS) and proposes an architecture that is applicable for training and operations.

ABOUT THE AUTHORS

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INTRODUCTION

Complexity is increasing on the battlefield. New reconnaissance and weapon systems, such as robotic systems, swarm systems and hypersonic weapons, are becoming part of the new battleground (Husain et al. 2018). Effective training tactics and support processes have to be developed and established for offensive and defensive measures (Black 2013). Powerful systems enable opponents to detect and attack Command & Control (C2) facilities, i.e., headquarters and command posts, more effectively, faster and over greater distances. Therefore, C2 facilities must reduce their signature so that they are harder to detect. Furthermore, they must be able to change their position often and quickly. Consequently, they must become smaller in size.

Where military operations are conducted with higher speed, decision cycles are decreasing. Additionally, units are assigned larger areas of responsibility (King 2019). Operations are conducted with joint and combined forces in multiple domains and cooperation with civilian actors is often required. Hybrid warfare – i.e., operations conducted with the aim "to disrupt, undermine or damage the target's political system and cohesion through a combination of violence, control, subversion, manipulation and dissemination of (mis-)information" (Wiessmann et al. 2021, 2) – adds the cyber space and the information space to the contested domains. Further development is needed to achieve situational awareness within these domains and to prevent or counter hybrid attacks. In sum, C2 facilities have to process vast amounts of information for coordination, command and the control of task execution in multiple domains. Increasing complexity of C2 and the requirement that C2 facilities become smaller in size, lead to the requirements that C2 must be able to become more efficient by fulfilling multiple roles. To some extent, these challenges are created by technology, i.e., technologies, reinforce the need for further developing military doctrines and procedures. Advanced technology is needed in order to cope with the challenges created by it.

Given the increasing complexity caused by the challenges of creating efficient military organizations, artificial intelligence (AI) methods are seen as a way to solve some of these problems.[1] For example, AI has demonstrated that it can master complex real-time strategy games (DeepMind 2021, among others). Such achievements have nurtured an expectation that similar results can be achieved for the military and help to (partially) automate C2 operations. However, the development of AI for C2 is not as straightforward as one might assume. For developing useful and usable technology, the right use cases have to be found and described. Military operations are not purely strategy games, i.e., they are neither Chess, nor Go or Starcraft II. They are affected by false and unknown information, otherwise referred to as "frictions and the fog of war" (Clauswitz 1832). The size of the theatre of operations is large and only partially observable, the number of possible actions is very high and the opponent's capabilities might even be partially unknown. Activities of the adversary actors are carried out at the same time, based on their own understanding of the domain. Own activities must not only be optimal with respect to achieving a well-defined goal, but they must also conform to rules of engagement. Before we can develop useful and usable technology, we have to

[1] Recent successes of AI have been achieved predominantly in the field of machine learning, in particular deep learning (Goodfellow et al. 2016) and reinforcement learning (Sutton & Barto 2018). These methods enable the creation of complex systems which would not have been possible otherwise. However, also symbolic methods of knowledge representation and reasoning are still on the market (Russel & Norvig 2021). It seems that they re-gain attention as the interest in causal reasoning rises (Pearl & Mackenzie 2018). Moreover, they can help to address problems of data scarcity as well as eXplainable AI (XAI). Instead of reducing the concept of AI to one specific methodology, we opt for treating AI as a toolbox, comprising symbolic approaches, sub-symbolic approaches (machine learning), and ensemble methods, by which symbolic and sub-symbolic systems can be combined (Zhou 2012).

identify feasible (i.e., relatively small and well-defined) tasks, assure that an environment for developing technical solutions – including sufficient training and test data – is available, and then select the most promising AI methodology. AI technology that is relevant for C2 support is to be designed and developed. Newly developed C2 technology must be integrated into the existing operational environment. Operational processes and technological tools must be mutually adapted, and operators must be trained. Therefore, an environment for developing AI C2 technology cannot only be a tool for software engineering, it must also provide the means for both understanding and developing the operational context, for continuously eliciting requirements, for training models and developing software, for integrating this software into the operational environment and lastly testing it. Our hypothesis as discussed in the paper is that constructive simulation (CS) systems substantially help to meet these requirements. They should be an essential part of an environment for AI C2 service development.

The outline of the paper is as follows: in the next section, we will give a concise introduction into CS. Then, we will discuss exemplary use cases of AI for C2 (AI4Ops). We will also describe how CS can contribute to AI development (Sim4AI, SimOfAI) and how, vice versa, CS can profit from AI C2 services (AI4Sim). Thereafter, we will define an architecture for integrating CS, AI services and C2 Information Systems (C2IS). We will describe the example of an integration and enumerate the lessons learned so far. Finally, we will sum up and give an outlook on future work.

A SHORT INTRODUCTION CONSTRUCTIVE SIMULATION

In the context of modelling and simulation, the following three types of simulation are usually distinguished (US Department of Defense, 2011, Çayirci & Marinčič 2009):

- Live simulations include real people operating real equipment, i.e., real people with real equipment move in a live range or urban area while weapon fire and its impact are simulated.
- Virtual simulations include real people operating simulated equipment, e.g., a pilot flying an aircraft in a flight simulator.
- Constructive simulations include simulated people operating simulated equipment.

Figure 1 shows the so-called Pyramid of Simulation, which relates different types of simulations with respective training audiences. As can be seen, constructive simulation is being used in Command and Staff Training (CAST) at War Training Centres and as Combat Simulation System.

In a constructive simulation, usually real people (a.k.a. operators) stimulate simulated equipment. The outcomes of the orders are simulated by the simulation. For example, in a context of logistics, an operator orders a tank truck to replenish a number of combat tanks at various locations. The constructive simulation moves the tanker truck to the various locations (along roads and across country as required) and executes replenishment without additional interference. Constructive simulations are being used in many areas such as education and training, concept development and experiments (CD&E), war gaming and decision support.

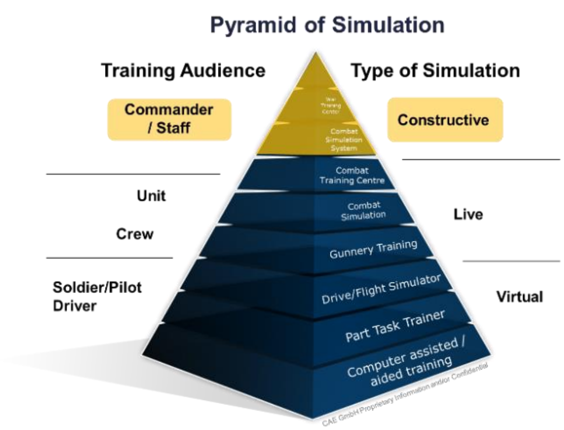

Figure 1. Pyramid of Simulation

Command and Staff Training (CAST)

Let us describe the usage of constructive simulation in the context of Command and Staff Training (CAST) in more detail. The objective of CAST is to train commanders and their staff within the complete range of their tasks under the most realistic conditions possible, without any influence from the simulation system and within the training and exercising concept of "train as you fight". This is achieved by decoupling the training audience from the simulation, as shown in Figure 2: the so-called primary training audience on the left-hand side – e.g., battalion or brigade commanders and their staff – are utilizing their original, operational equipment, possibly in a real command post in the field. Parts of the equipment can be paper maps, Command & Control Information Systems (C2IS) and voice communication systems. To support exercise analysis and debriefing, video and audio recordings in the command post capture interactions between the training participants.

Figure 2. Exemplary CAST Setup

Commanders of sub-units (e.g., company commanders) are typically located closely to the simulation and not in a command post. Often referred to as a secondary training audience, they receive orders from the primary training audience, plan their mission and – together with simulation operators – define and enter commands into the simulation. The simulation executes the simulation commands in real-time, taking into account various aspects such as weather and terrain conditions, and presents the outcome of the simulation at the operator stations. The secondary training audience and simulation operators evaluate the current, simulated situation and provide reports to the primary training audience in the same way as in reality, e.g., using C2IS and voice communication systems.

AI-SUPPORTED C2 AND CONSTRUCTIVE SIMULATION

Now that we have laid the foundation of our constructive simulation domain, we will describe to which ends and how AI can be incorporated into the simulation.

AI for Situational Awareness and Assessment

Situational awareness and assessment as key requirements for Command & Control (C2) demand a situational picture. The situational picture should be true and complete – that is, it should be consistent, contain all relevant information, but no false information. Simultaneously, it should neither be redundant nor contain irrelevant information. Finally, it should be easily accessible for the operator and not demand unnecessary cognitive effort.[2] AI technology can be designed to support the creation of situational pictures that meet these requirements.

Let us assume that we are provided with a situational picture, i.e., with a map, on which detected *Battle Space Objects* (BSO) are presented by symbols. These could be drawn from the APP-6 standard (NSO 2017).[3] Regarding the red

[2] The operational picture should follow the maxims of cooperative information exchange according to Grice (1989).
[3] For creating a situational picture, sensor data have to be fused and processed in order to detect and classify BSOs which are to be represented by symbols on a map. Furthermore, the map itself has to be analyzed so that relevant terrain features, including roads, obstacles, etc. are detected. Sensor data fusion, object recognition and classification are paradigmatic AI tasks to be solved in particular with machine learning techniques. However, constructive simulation cannot contribute to the development of such services. It starts on a later stage of the creation and analysis of an operational picture, where BSO representations are already available.

forces, the situational picture can be expected to be incomplete at best, as in most cases not all red BSOs have been detected. The task is, thus, to aggregate and enrich available information. Aggregation is the assignment of detected BSO to units of higher order. Enrichment is the addition of information on not yet detected BSOs. For example, let us further assume that we have detected two red battle tanks on two sides of a forest. We know that red battle tanks occur in platoons of three tanks each, and that three platoons plus a company leader form a company. Moreover, we know that the forest is an obstacle that shall not divide a company. That is, all platoons of a company must be either on the one or on the other side of the forest. We can thus conclude, that the two tanks must belong to two different companies, and that nine additional tanks must be expected on each side of the forest. We can enrich our situational picture accordingly. This kind of reasoning can be automated with a rule-based approach that takes into account detected BSOs, doctrinal information regarding terrain features (in particular, obstacles) and operational spaces of units, as well as expectations regarding the red order of battle (ORBAT) (Stucken et al, 2021a). In addition to rule-based reasoning, approaches based on unsupervised learning can generate clusters of detected BSOs. Clusters can provide information on the red command lines, as well as the center of gravity. Further describing the clusters by identifying their capabilities can support the operator in identifying possible intentions that require these capabilities (Stucken et al. 2021b). That is, services for information aggregation and enrichment can support the operator in achieving comprehensive situational awareness and in assessing the situation without easily ignoring possibilities due to some kind of bias.[4]

For information aggregation and enrichment as sketched above, we ignore the time dimension and analyze merely snapshots of the situation. However, situational awareness can be further improved by taking time into consideration. In particular, identity management deals with the problem that the presence of a BSO can be reported by different reporters at different points in time. Multiple reports can lead to the multiple appearance of a BSO on the map. The task of the operator is to recognize which symbols refer to the same BSO and to clean the situational picture accordingly, i.e., to delete all but one symbol for each BSO. AI technology can support this task, e.g., by determining which symbols *must* refer to the same BSO, which *can* and which *cannot*. In addition to identity management, situational changes of time can be analyzed for recognizing activity patterns. The recognition of activity patterns supports the assessment of the opponent's intentions.

An aggregated, enriched and cleaned situational picture can be compared to alterative situational pictures that represent the most likely course of action and the most dangerous course of action. The similarity and distance to the alternative pictures can be considered a risk indicator.

Information aggregation, enrichment and cleaning are information management tasks. Further tasks include anomaly detection and role-specific information retrieval and filtering. Information retrieval and filtering are crucial in particular in complex, multi-dimensional settings, in which an operator can be easily overtaxed by too much irrelevant information. Various AI approaches can be followed, among them rule based and machine learning approaches (Cawalla & Schmitz 2021, Ahmed et al. 2020).

How can CS contribute to AI service development (Sim4AI)? Firstly, CS systems can provide training and test data. They provide both a complete and true situational picture of an exercise and the situational picture of the training audience (the so called "perceived truth", see below), which is (presumably) incomplete and can also contain falsities. Aggregation, enrichment and cleaning have to be performed on the perceived truth. The ground truth serves as a reference for validation. Secondly, CS serves as a realistic evaluation environment. AI services can be integrated into the C2IS of training audiences in order to support operations (AI4Ops). During an exercise, the training audience applies the services and evaluates their usefulness and usability. Thus, CS enables developers to test AI services in an environment close to "the wild". They can conduct quantitative and qualitative interviews with operators and determine the perceived usefulness and ease of use (Davis 1989, Davis et al 1989), among other measurements. Therefore, a CS system can substantially support an iterative human-centred design process, which comprises design, prototypical implementation and practical testing of new services (ISO 2019).

Not only can CS support the development of AI C2 services, but, vice versa, the services mentioned above can also improve CAST exercises that make use of CS (AI4Sim). In various discussions, operators of CS systems stressed the potential usefulness of aggregation and enrichment services for after action reviews. Aggregation and enrichment services can be used to display the entire space of possible situational pictures. Alternative pictures can be used for

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[4] Various kinds of bias that can negatively affect situational assessment have been described by Kahnemann (2012).

explaining to the training audience which possible courses of action they easily ignored. Thereby, the training audience can be made aware of their decision biases.

Developing a Ground Truth vs. Reported Truth Model

A very important aspect of integrating AI, CS and C2IS is the consideration of ground truth versus reported truth. The latter comprises both the reported/perceived truth of the blue forces and the reported/perceived truth of the red forces:

- Ground truth represents the current situation in the simulation.
- Blue-Force-Tracking (BFT) truth: simulated elements are reporting their current positions and statuses. Depending on the capabilities or settings of the simulated systems, the BFT-reporting can differ from the ground, emulating delayed or interrupted communication.
- Perceived truth of the red forces refers to the results of reconnaissance: as in the real world, the perceived truth depends on the capabilities of simulated sensors, weather and terrain conditions. It can differ from the ground truth, emulating delayed or even interrupted communication.

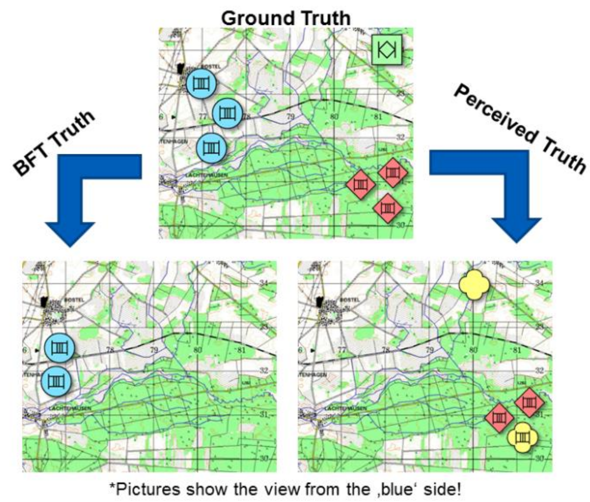


Figure 3. Ground Truth vs BFT Truth vs Perceived Truth

The three concepts are depicted in the Figure 3, showing the situation as seen from the blue side: the reported BFT positions ("BFT truth") are delayed to the ground truth. One position is not available at all. Also, the reported reconnaissance ("perceived truth") differs from the ground truth, showing only partial information for some elements, indicated by the yellow symbols, and in one case also delayed positional reporting,

When integrating AI technology with simulation systems, the differences between ground, BFT and perceived truth have to be taken into account. Just like a human operator, an AI engine should not act on the ground truth, but on the reported truth. Ground truth is always true, complete and timely. BTF truth and perceived truth are not always complete, not always in time and they can contain false information as well. (Therefore, the term "truth" can be considered misleading or at least imprecise.) It is a major challenge to include false but realistic information into the situational pictures. "Realistic" means that the false information is of a kind that can occur in situations such as the one constructed for the exercise. Moreover, falsities must not follow simple patterns that can be detected too easily. One way to include false information would be to design a deceiving agent for generating false but realistic information. The challenge for the operators is to detect false information. The challenge for C2 services is either to detect false information or to provide analyses which are robust regarding the influence of falsities. Aggregation by clustering can be an example for such an analysis.

AI for Strategy Development and Believable Behavior Modeling

Ambitions regarding AI and C2 go beyond information management. Expectations are set for automation and the discovery of optimal strategies and tactics which are to be executed at high speed. An obstacle for automated C2 solutions is the high complexity of the battlefield environment: the battlefield itself has a complex structure and many different courses of action are possible in each situation. The environment is uncertain as it is neither deterministic nor fully observable. Agents might even have to cope with false information. It is an adversary environment with opposing agents acting concurrently. The situation evolves continuously (the battlefield has no discrete states) and dynamically (the battlefield can change even if an agent does not act). Every decision can have long term effects. For modelling intelligent agents, the environment is thus as difficult as it can get (Russel & Norvig 2021, 43ff). Therefore, a challenge is to simplify the environment and define "games" which are realistic and relevant for military practice, but still manageable for current AI technology.

Information management, including aggregation, enrichment, etc., is a step towards simplifying the environment. It contributes to a comprehensive and simple situational picture. The association of BSO clusters with capabilities and possible intentions and the recognition of activity patterns link the situational picture with the realm of possible courses of action. They provide clarity on the options for action of the own forces as well the red forces. A further reduction of complexity can be achieved by modelling complex actions that can be considered essential and highly standardized. Water crossing – a sequence of reconnaissance, artillery fire, covering, bridge laying, crossing and formation of a bridge head – would be an example. The automatic execution of complex standard actions must be believable and doctrine-conformant. Relatively simple, declarative techniques, which have proven useful in Game AI, can be promising, among them behavioural trees (Yannakakis & Togelius 2018). CS exercises would immediately profit from automation of standard actions as automation would relieve both system operators and the secondary training audience from executing atomic actions manually one by one (AI4Sim).

Usually, CAST exercises are not competitions of red vs blue forces, trying to defeat each other. The aim of these exercises is not to win a war game, but to create situations only for the training of the blue forces. However, beyond their actual purposes, CS can be used as war gaming environments (Sim4AI). For this purpose, wining conditions are to be defined for training scenarios. Red and blue forces act within the "ground truths" of these scenarios, but they see only their "reported truths". Possible "game moves" would be aggregated standard actions as described above, which relate to the forces' capabilities. Game playing agents can be trained by reinforcement learning, thereby discovering winning strategies (Sutton & Barto 2018).[5] The ultimate outcome of such an experiment would be a decision support system for advising commanders (AI4Op). However, even without aiming at a decision support system, the results of reinforcement learning experiments can be interesting. They would be valuable if they could reveal weak spots of the own or the opponent's tactics. If simulation of new military technology and new capabilities are added to the environment, then the experiments can contribute to developing successful processes and tactics for bringing these technologies to their full potential (SimOfAI).

ARCHITECTURE

In the following, we will outline a basic system architecture. The architecture shown in Figure 4 on the next page covers the different areas identified above and indicates the data flow between the components.

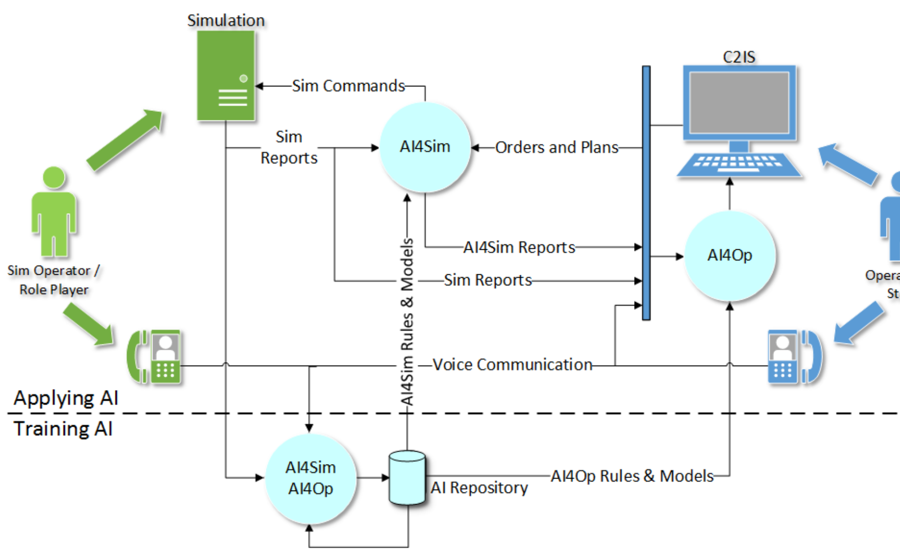


Figure 4. System Architecture and Data Flow

[5] It has to be assured, that game playing agents cannot exploit technical features ("bugs") of the simulation environment. If their strategies relied on such features, then the strategies could not be successfully applied outside of the simulation.

We distinguish between the application and the training of AI technology. The following components enable the application of AI, e.g., for decision support, automation of simulated forces and war gaming:

- Simulation: the simulation component emulates the real world. It receives input from simulation operators, role players (secondary training audience) and the AI4Sim components. It sends data to the components of AI4Sim, AI4Sim/AI4Op and C2IS. In this architecture, we assume that the simulation will not receive any orders or plans directly from the C2IS, even though this might in fact happen in existing implementations.
- C2IS represents any type and any number of Command & Control Information Systems. The component receives inputs from the operational staff, AI4Sim, AI4Op and simulation components. It sends data (i.e., orders and plans) to the AI4Sim components. As mentioned above, a direct exchange of orders and plans from the C2IS to the simulation was omitted on purpose.
- AI4Sim: the AI4Sim components support the simulation system, e.g., by automating simulated processes. This includes but is not limited to combat and logistics, as well as the analysis of orders and plans received from a C2IS and their translation into simulation interpretable commands. AI4Sim receives inputs from the AI Repository, C2IS and the simulation. It must be stressed that AI4Sim utilizes simulation reports rather than the “ground truth”. Such reports include, e.g., position and status updates of own and allied forces as well as reconnaissance reports. Thus, they represent the Blue Force Tracking (BFT) truth and the perceived truth as outlined above. AI4Sim sends data to C2IS and simulation components.
- AI4Op: this AI component is intended to support the operational C2IS system. It receives input from the AI4Sim, simulation and voice communication components. It analyses the incoming data by applying AI4Op rules and models from the AI Repository, and it provides the corresponding results to the C2IS.
- Voice Communication: in the context of CAST, voice communication is used between the primary training audience and subordinate leaders, i.e., simulation operators (role players). If applicable, speech data recorded from voice communication can be used by the AI4Op component for training speech recognition systems and natural language processing systems.

On the lower part of the diagram in Figure 4, two further components are named. They are predominantly associated with the training of AI:

- AI4Sim/AI4Op: the components subsumed at this node are used to determine rules and learn models for the AI4Sim and AI4Op components in the upper part of the diagram. AI4Sim/AI4Op receives simulation reports and voice communication as input data for further analysis and training. Resulting rules and models are stored in the AI Repository.
- AI Repository: the repository provides rules and models to the AI4Sim and AI4Op components.

It is noteworthy that services of the AI4Op component can also be used independently from simulation and that A4ISim reports in a purely operational context. Consequently, they would utilize real sensor data to support real world operations.

INTEGRATION AND LESSONS LEARNED

Integration of the GESI Simulation System and a C2IS

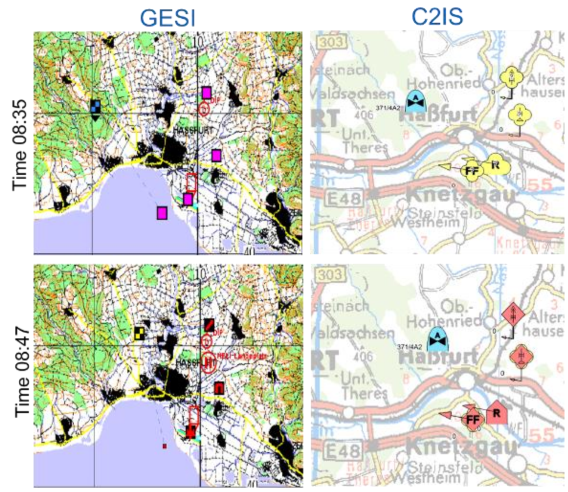
In the following section, we will provide an example for the integration of the GESI CS system with C2IS in the context of Command and Staff Training (CAST).[6] GESI was initially developed for training military leaders. However, the target group for training has been enlarged. Besides military audiences, the target group meanwhile also comprises of civilian crisis managers and their staff, both for training purely civilian emergency management scenarios and scenarios of civil military cooperation (CIMIC). GESI has been developed towards a comprehensive training environment for civilian and military operations in multinational scenarios including all levels of command.

In order to support the concept of “train as you fight”, GESI has been integrated with a large variety of C2IS, thereby utilizing various formats and technologies. The focus is on the harmonization of troop structures, and the exchange of position data, reconnaissance results and orders. For the harmonization of troop structures, several (to some extent:

[6] GESI is a product of CAE.

proprietary) interfaces have been implemented. The most promising standard format for this purpose is the Military Scenario Definition Language (MSDL, SISO 2008, Wittman 2009). MSDL has been designed to support scenario development with the ability to create scenarios that can be shared between simulation systems and C4I (command, control, communications, computers, and intelligence) devices. It is under continuous development.

To provide Blue-Force-Tracking data to C2IS, interfaces based on NFFI (NATO Friendly Force Information, STANAG 2017), C-BML (Coalition Battle Management Language, SISO 2014, Heffner et al. 2010) and HLA Evolved (High Level Architecture Evolved, IEEE 2010) are being utilized. To provide reconnaissance data to C2IS, various interfaces have been implemented, e.g., based on C-BML and HLA Evolved with extensions to the RPR FOM 2 (Real Time Platform Reference Federation Object Model, SISO 2015).



*Pictures show the view from the ‚blue' side!

Figure 5. Reported Truths

Figure 5 depicts two simulated situations at two different points in time: 8:35 and 8:47. In the left column, the situation is depicted as a GESI operator station, with square symbols in different colours. In the right column, a view on the same situation is given via a C2IS to the training audience. This view applies APP6 symbology. In the situational picture of the C2IS at 8:35, red BSOs have been identified only partially, indicated by the yellow symbols, i.e., the affiliations are unknown. Later, at simulation time 08:47, previously unknown affiliations are now clear. Accordingly, the yellow symbols have been exchanged by red symbols (please note that for testing purposes, the simulation includes an artificial lake which is not shown in the C2IS).

Integrated C2IS can provide their own proprietary AI services without making use of the CS system as a development environment. So far, we use GESI to provide situational pictures – ground truth and perceived truth – as training and test data for experiments in information management, in particular for aggregation and enrichment (Stucken et al 2021a, 2021b). This work is well advanced. Next step will be to evaluate aggregation services with operational personnel in a CAST environment. Further experiments in identity management are planned. We do not yet use GESI as an environment for running experiments in reinforcement learning. In that regard, we are currently gaining experiences with a simplified, game-like environment at FKIE. In the mid-term, the results are to be transferred to CS-enabled CAST scenarios.

Lessons Learned so far from Integrating CS, C2IS and AI

The integration of diverse systems and technologies such as CS, C2IS and is a complex and challenging task. Here are some lessons learned:

- User involvement is essential. This applies to all phases of the integration, design, development and testing, and ensures that the integration focusses on what is needed rather than what is technically possible or nice to have.
- To effectively involve users, user communities must be brought together, among them the simulation-based training and C2 communities. They represent different worlds, with different requirements and different expectations. C2IS are operational systems, mostly with a stringent design that focusses on specific purposes. Simulation systems on the other hand are emulating the real world – often in an abstract manner. They are used for different purposes.
- In order to tackle complexity, the focus should be on the use case and a specific domain (Evens 2003).
- Follow an iterative development approach with many, clearly defined and reproducible tests. Early testing can reveal existing or potential bottlenecks such as limited reports processing per cycle, which can then be reviewed, its severity for the use case assessed (together with the user) and then managed by adapting the interface (cf. ISO 2019).

- Utilize standard protocols. This will lead to reduced development time and costs. Nevertheless, as the past has shown, even if a system supports a certain standard, it does not automatically mean that the goal of the integration can be achieved through a standardized protocol.
- Extend a standard if necessary, but keep compatibility. Often, it is necessary to exchange additional data. Here, it is preferable to extend an existing standard rather than change the semantics. A good example is HLA Evolved, which can easily be extended through the definition of Base Object Models (BOM).
- Time synchronization between simulation and C2IS remains a challenge. Simulation systems are usually flexible, allowing to freely set the simulation date and time. They can run faster, slower or in real-time and allow the resetting and restarting of the simulation. Operational systems, however, are often bound to the wall clock time of the real world. This means, that time advancement takes place in real-time only.
- The generation of realistic and plausible falsities is still a challenge. Frictions of war can be conditioned by false information. They must be considered by information management. However, falsities are not arbitrary. They must not match unrealistic, easily recognizable patterns.
- Data derived from simulation exercises can be regarded as very valuable training and test data as they can be considered realistic and it can be hard to receive comparable amounts of realistic military C2 data from other sources. (Data are only valuable if they are realistic.)
- In simulation exercises, a lot of data are generated. However, not all of these data can be fruitfully used for training and testing. For example, voice communication can be recorded. It would be tempting to use the recordings for training automatic speech recognition systems. However, CS systems do not automatically provide the transcriptions required for training. The effort to transcribe the recordings so that they can be used for training would be unreasonably high.

CONCLUSIONS

We presented an architecture for integrating C2IS, a CS system and AI services. The aims are, firstly, to use a CS system as an essential part of a development environment for AI C2 services (Sim4AI, SimOfAI) and, secondly, to use AI services for enhancing simulation (AI4Sim). The architecture is in particular applicable for use cases such as CAST, war gaming and experiments. For simulation-based/enhanced decision support, the architecture could be extended by at least two additional data flows: firstly, provision of current positional and status updates of own and allied forces and reconnaissance reports from the C2IS to the simulation, and, secondly, a feedback line from C2IS to the AI4Op component.

Currently, we are running experiments mainly in information management (AI4Op). To this end, we refer to ground truth situational pictures and perceived truth situational pictures captured from the simulation. Good results have been achieved in particular regarding information aggregation and enrichment. We are planning to define manageable scenarios for conducting experiments in reinforcement learning. The goals of these experiments will be to discover successful tactics, to evaluate current tactics and doctrine and to estimate the impact of new technology on the battlefield (Sim4AI).

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